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Darwin's study at Down House in Kent, where he co-opted his family to help with his research.

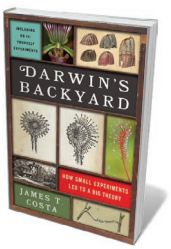
EVOLUTION

Darwin's domestic discoveries

Henry Nicholls relishes a book on how the biologist's home became a lab for dazzling experimentation.

On my hard drive I have a folder entitled "Darwin at Home". In it is an outline for a book I've always wanted to write — on the sometimes wacky, mostly brilliant experiments that Charles Darwin got up to at Down House in England, in the midst of boisterous family life. Evolutionary biologist (and trustee of the Charles Darwin Trust) James Costa has saved me the trouble. His book, *Darwin's Backyard*, is a passionate but balanced celebration of the Victorian scientist's lifelong obsession with enquiry and how the fields and meadows around his home were a microcosm of the wider world.

There are many reasons to love Darwin's 40-year programme of research. For a start, there is the sheer breadth of his interests: the spirited chemistry of his schooldays (which earned him the nickname 'Gas'), the eight-year observational study of barnacles to hone his taxonomic skills, the experiments in seed viability to illuminate patterns of species distribution. And there was much more, from the dissection of the dizzyingly complex, insect-facilitated sex lives of flowering plants to the idea of casting "the fancy" (the breeding of pigeons) as an analogy for the power of selection; the study of how plants move; and a four-decade project revealing the soil-shifting magic of earthworms.



Darwin's Backyard: How Small Experiments Led to a Big Theory
JAMES T. COSTA
W. W. Norton: 2017.

Costa devotes each chapter to a different line of Darwin's enquiry, arranged roughly chronologically. But he flits between projects, too, mirroring how Darwin often had many on the go. At one point in the 1850s (the decade that closed with the publication of *On the Origin of Species*), Darwin had frog eggs in the hallway, seeds in the cellar, duck feet dangling in a 'snailery', dissected flowers beneath the microscope, fenced plots on the lawn and pigeons in a homemade dovecote.

There is much to admire in Darwin's work ethic. In spite of the mysterious illness that plagued his life after he returned from his 1831–36 voyage on HMS *Beagle*, he was relentlessly inquisitive, engrossed in one obsession or another right up to his death in 1882. He was highly inventive, coming up with simple but ingenious experimental designs such as the "weed garden", a trial that revealed the extraordinary rates of death in nature and, hence, the intense struggle for survival. He was also receptive: when his eight-year-old son Francis suggested that seeds might be carried across oceans in the crop of a dead, floating bird, Darwin sacrificed a pigeon from his dovecote and dropped it into a tank of salt water for a month. The seeds in its crop later grew "splendidly".

In almost all his endeavours, Costa reveals, Darwin demonstrated "stick-to-itiveness". For instance, when he investigated sexual reproduction in purple loosestrife (*Lythrum salicaria*), which can have one of three types of flower, he performed every possible cross to record differences in fecundity. He was playful, too. When he scrutinized bumblebee "buzzing places" (revealed later to be spots in which male bees release pheromones), he enlisted his children to map out the insects' travels. Leonard, four at the time, later described the experience as a game in which "my father was like a boy amongst other boys". Costa celebrates Darwin's humanity without tipping over into hagiography.

Darwin's obsessive "experimentising" reveals much about how to do good science. Almost all his investigations began with open-minded observation, from which he framed questions. His inspiration came from multiple sources: the literature, observation and the network of amateurs and professionals with whom he kept up a vigorous correspondence. He often sought multiple, complementary lines of evidence. In his work on the carnivorous sundew plant *Drosera rotundifolia*, for instance, he generated several predictions to test his hypothesis that it trapped insects to obtain nitrogen.

Among these were that the plant should show a preference for nitrogenous over non-nitrogenous foods, and that the droplets that it secreted should have "some ferment analogous to pepsin", a digestive enzyme. Thus, one answer would throw up a multiplicity of new questions like the diverging branches of a tree. "My mind seems to have become a kind of machine for grinding general laws out of large collections of facts," wrote Darwin in his autobiography, published in 1887. ▶

Darwin embraced challenges to his theory of evolution by natural selection. Witness his stunning research into the construction of honeycomb by honeybees. Along with close observation, Darwin harnessed complex mathematics, comparative biology and collaboration with naturalist William Tegetmeier. In an ingenious experimental twist suggested by Tegetmeier, the bees were provided with red-tinted wax to reveal the building process. Thus Darwin demonstrated that honeybees pivot on a point to create a cylindrical chamber, then rework it to incorporate the dead space. The result is a hexagon made "from a few very simple instincts".

"Darwin frequently deployed the crowdsourced citizen science of his day."

Darwin also frequently deployed the crowdsourced citizen science of his day. He invited the public to send in observations of rare events. He had a hunch, for instance, that insects (and probably bees) must occasionally visit the bee orchid *Ophrys apifera*, and asked readers of the *Gardener's Chronicle* for evidence of insect pollination in this species. Although that enquiry drew a blank, he was right. In England, self-pollination is the flower's main mode of reproduction; in Mediterranean populations, bees occasionally facilitate crosses between different plants.

Today, as Costa reminds us, the incorporation of careful controls, large sample sizes, replication and statistical analysis have improved the rigour of experimental design and the robustness of conclusions. He also describes how today's scientists are using methods such as isotope analysis and DNA sequencing to add weight to Darwin's conclusions beyond his wildest imaginings. *Darwin's Backyard* drives home how science is a cumulative, constantly evolving endeavour.

All of this makes Darwin's experimental world a wonderful teaching tool, especially given that many of his trials lend themselves to replication. Fortunately, each chapter closes with Darwin-inspired experiments to try at home. Costa more than achieves his stated goals of revealing the evolution of Darwin's insights and the relevance of his methods now. As for me, I've dragged my "Darwin at Home" folder into another called "Backburner". ■

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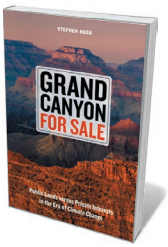
CONSERVATION

The great US land grab

Kierán Suckling extols a study of looming threats to the country's publicly owned territory.

In *Grand Canyon for Sale*, environmental journalist Stephen Nash delivers a nuanced, comprehensive, surprisingly up-to-date review of the threats facing the United States' 2.5 million square kilometres of publicly owned land. That includes national parks, forests, deserts and wildlife refuges — sites Nash calls "28 percent of the national dirt". Here are direct, captivating stories centring on efforts to protect Native American culture, endangered species and ecosystems; the actions of rangers and armed militias; the aims of US President Donald Trump's administration; and, always, politics and money.

Although relevant to all US public lands, and many elsewhere, the book focuses on the almost 23,000 square kilometres of public land centred on Arizona's Grand Canyon. Its subtitle, "Public Lands Versus Private Interests in the Era of Climate Change", is apt, but the last phrase is extraneous.



Grand Canyon for Sale: Public Lands Versus Private Interests in the Era of Climate Change
STEPHEN NASH
University of California Press: 2017.

The implications of climate change for science and land management are covered well here, but are not the overarching theme. This is a strength. Climate change too often dominates conservation discussions, and can obscure the massive, pervasive and immediately actionable effects of habitat destruction and cultural disruption. *Grand Canyon for Sale* is fundamentally about the use of power politics to hijack public values, heritage and acreage for private gain.

Nash's discussion of invasive species is